
Ahmadreza Talebian, Bo Zou
University of Illinois at Chicago

RailTokyo 2015 Conference
March 23-26, 2015
Outline

• Background
• The model
  – Preprocessing
  – Bargaining game with complete information
  – Bargaining game with incomplete information
• Concluding remarks
Background

- Passenger rail resurgence in the US
- High performance rail systems (HSR and HrSR services)
- Midwest: existing single track lines are being upgraded to accommodate trains running at a maximum speed of 110 mph
Background

• Freight side:
  – 15% increase in Class I Railroads’ revenue ton-miles between 2001 and 2011
  – About 6800% increase in originated carloads of crude oil on Class I Railroads
Background

• Challenges of Higher Speed Rail lines
  • Single tracks with siding (meets and overpasses)
  • Shared passenger and freight use (negative impacts on capacity utilization of speed heterogeneity)
  • High speed passenger trains operating at 110 mph (on-time performance is essential)

It is important to develop a capacity allocation mechanism taking into consideration different characteristics of the US railway market.

The first sequential bargaining approach to capacity allocation in the US rail system...
The model

• Issues to be considered:
  – Complementary feature of rail tracks
  – Endogenous capacity
  – Amtrak’s priority (Public Law 110-432)
  – Temporal variations in passenger demand
  – Train schedule inconvenience to passengers
  – Freight railroads keep their operating and financial information confidential
The model

• Preprocessing stage
  Step 1: Developing initial passenger train schedules
  Step 2: Generating feasible passenger train schedules
  Step 3: Solving the freight train scheduling problem
  Step 4: Establishing utility values

• Equilibrium determination stage
  Complete information
  Incomplete information
The model

Preprocessing stage

Step 1: Developing initial passenger train schedules

• Talebian and Zou (2015):
  • Hypergraph based method: captures the interaction effects of resource transitions
  • Minimize schedule delay, given Passenger Preferred Departure time

The model

Step 1: Developing initial passenger train schedules

Preprocessing stage

- Schedule delay: The difference between one's desired departure time and the actual departure time.
The model

Preprocessing stage

Step 1: Developing initial passenger train schedules

- Each O-D pair has a passenger demand profile (Preferred Departure Time)
- Passengers are served by a predetermined number of trains

![Diagram showing passenger demand and train boarding times]
The model

Preprocessing stage

Step 1: Developing initial passenger train schedules

- Passenger demand is elastic w.r.t. schedule delay
- Find the number of passengers travelling between each origin-destination pair \( pq \) and prefer to depart at each time period \( s \):

\[
d_s^{pq} = D_s^{pq} \left(1 - e_{d/w} \left( \frac{w_{s,new}^{pq}}{w_{s,org}^{pq}} \right) \right)
\]
Step 2: Generating feasible passenger train schedules

• Define
  • Earliest allowed shift (on the left-hand-side of the initial train departure)
  • Latest allowed shift (on the right-hand-side of the initial train departure)

• Find all feasible schedules using the same hypergraph based model as in step 1
The model

Preprocessing stage

Step 3: Solving the freight train scheduling problem

- Freight train scheduling is less precise and stringent in the US
- Freight trains are inserted among passenger trains (scheduling priority is granted to passenger trains)
- Minimize total freight side cost, which consists of foregone demand cost, train en-route delay cost, and train departure delay cost
The model

Preprocessing stage

Step 4: Establishing utility values for passenger and freight sides

\[ U_{\text{passenger}} = \text{operator revenue} - \text{passenger schedule delay cost} - \text{operating cost} \]

\[ U_{\text{freight}} = \text{operator revenue} - \text{track maintenance cost} - \text{operating cost} \]
Equilibria

Solving the Rubinstein sequential bargaining game

Stage 1

Stage 2

Stage 3

Stage 4

Stage 5

Stage 6

Stage 7

Stage 8

PRA

FRR

(s₁, SDP₁)

AC₁

PRA

Reject

Accept

(uₛ₁^P + SDP₁ - AC₁, uₛ₁^F - SDP₁ + AC₁)

(s₂, AC₂)

SDP₂

PRA

FRR

Reject

Accept

(δ_p(uₛ₂^P + SDP₂ - AC₂), δ_f(uₛ₂^F - SDP₂ + AC₂))

(s₁, SDP₁)

FRR
The model

Equilibrium determination

Solving complete information bargaining game

• Stationary structure of the game is employed to solve the game

• Equilibrium: a schedule maximizing the sum of utilities of the passenger rail agency and the freight railroad (independent of the player initiating the game)

• Net transfer from FRR to PRA:

$$SDP_1 - AC_1 = \frac{u^P_{S1} - \delta_F u^F_{S1}}{1 + \delta_F}$$
The model

Equilibrium determination

Solving incomplete information bargaining game

• Class I freight railroads consider their operating and financial information highly critical to profitability and thus confidential

• A simplification: two-level bargaining
  • Upper level: price bargaining for each passenger train schedule
  • Lower level: schedule bargaining given the price for each schedule
The model

Equilibrium determination

Solving incomplete information bargaining game

• Upper-level: price bargaining
  • PRA does not know FRR’s utility but assesses it according to a distribution on $[u_{si}^F, \bar{u}_{si}^F]$
  • Bayesian Nash equilibrium for a game consisting of two sub-games

$$p_{si}^1 = \begin{cases} 
\delta_F u_{si}^P - u_{si}^F (1 - \delta_F) & 2u_{si}^F \geq u_{si}^P + \bar{u}_{si}^F \frac{1 + \delta_F}{1 - \delta_F} \\
\frac{1}{2} (u_{si}^P (1 + \delta_F) - \bar{u}_{si}^F (1 - \delta_F)) & 2u_{si}^F < u_{si}^P + \bar{u}_{si}^F \frac{1 + \delta_F}{1 - \delta_F}
\end{cases}$$
The model

Equilibrium determination

Solving *incomplete information bargaining game*

- **Upper-level: price bargaining**
  - Using backward induction, the formulation for solving a game consisting of $N$ subgames is developed

- **Lower-level: schedule bargaining**
  - Given the price of each schedule, PRA and FRR bargain to determine an equilibrium schedule
  - The schedule bargaining is a game with complete information, as the price for each schedule and PRA’s belief in FRR’s utility are determined at the upper level
Concluding remarks

• Proposed the first sequential bargaining game model to identify capacity shares and associated charges on shared use rail corridors in the US context

• Bargaining game with complete information:
  – A schedule maximizing the sum of utilities of the passenger rail agency and freight railroad is the equilibrium solution
  – The equilibrium schedule is independent of the player initiating the game

• Two-level price and schedule bargaining extension for incomplete information

• On-going research: numerical analysis
Thank you!

Questions?
Backup slides
Background

• Capacity allocation mechanisms:
  – Administrative
    • a set of decision criteria to allocate train paths to operator
    • employed in rail networks fully owned and controlled by government
    • the infrastructure manager places a value upon each train path
    • then train operators decide whether they are willing to take an offered path
  – Market based approaches
    • reveal operators’ willingness-to-pay
Background

Capacity allocation in the US

- Administrated: no incentive for operators to seek for a more efficient use of capacity
- Value-based: congestion impacts and scarcity of capacity are mostly neglected
- Market-based essentially: applies to open access markets
- Capacity is mostly allocated through negotiation

The first sequential bargaining approach to capacity allocation in US rail system